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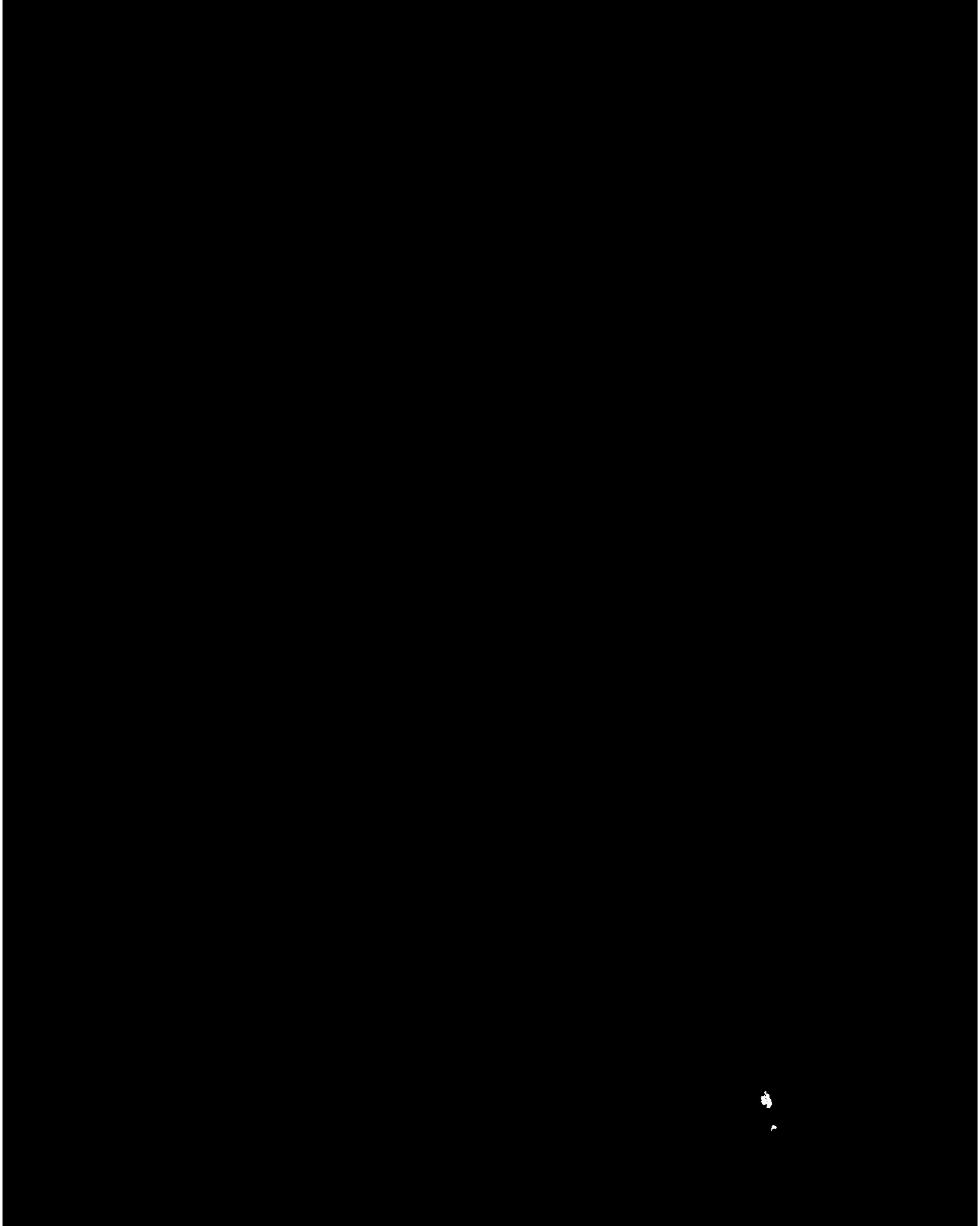

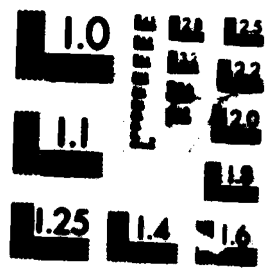

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DESIGN AND CHARACTERISTICS OF A LIQUID AEROSOL GENERATOR

S.S. TI and J.D. INGRAM

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DESIGN AND CHARACTERISTICS OF A LIQUID AEROSOL GENERATOR

S.S. Ti and J.D. Ingram

S U M M A R Y

A liquid aerosol generator of the dispersion type was designed, constructed and calibrated. For the polydisperse kerosene aerosols, the mean droplet diameters were found to be inversely proportional to the vapour pressures.

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1. INTRODUCTION

Flames are known to be natural sources of heat, visible and infrared radiations. They are usually produced by the ignition of solid, liquid or gaseous fuels.

More recently, considerable interest has been devoted to the combustion of droplets of liquid fuels. Studies in the field of spray flames require a system to generate liquid aerosols of the desired size distributions.

There are generally two broad categories of liquid aerosol generators(ref.1):

(a) Dispersion type in which droplets are produced from a liquid jet at an orifice or a nozzle.

(b) Condensation type in which aerosols are formed by the gradual cooling of the supersaturated vapour.

The dispersion type, which is relatively easy to design and manufacture, usually produces aerosols with a wide distribution of droplet sizes. On the other hand the condensation type allows the generation of droplets with relatively uniform size distributions.

The choice of the type of liquid aerosol generator depends on the specific research interest, and the availability of resources.

For the purpose of producing a large aerosol flame which can be used as an infrared decoy, the requirement of uniform size distributions is not mandatory and the dispersion type appears to be sufficient.

This paper reports the design and the characteristics of a liquid aerosol generator; and the empirical relationship between the mean droplet diameters and the vapour pressures of the kerosene aerosols.

2. DESIGN

The design of the liquid aerosol generator was based on the following considerations:

(a) Ability to vary the mean droplet size by a relatively simple adjustment of the aspirating gas pressure and the fuel flow rate.

(b) Capability to generate large aerosol clouds of liquid fuels of substantial difference in surface tension, viscosity and density.

(c) Continuation of aerosol generation for a duration of approximately 30 s.

The dimensions of the liquid aerosol generator were approximately calculated by assuming a non-turbulent flow of the liquid fuel and the aspirating gas, and using the elementary physical principles outlined below:

The fuel flow rate is determined from the Hagen-Poiseuille formula:

$$\frac{V}{t} = \frac{\pi P r^4}{8 n l},$$

where V is the volume of the liquid fuel in cm^3 flowing through a capillary tube of length l cm and radius r cm in t s, n is the viscosity in poises and p the pressure difference in dynes cm^{-2} between the two ends of the capillary tube.

The dimensions of the aerosol generator housing and the nozzle through which the aspirating gas flows are estimated from the Bernoulli equation for the gas flow of the same level:

$$p + \frac{1}{2} \rho v^2 = \text{constant},$$

and the continuity law:

$$\rho A v = \text{constant},$$

where p is the pressure, ρ the density, v the velocity of the gas and A is the cross-sectional area of the passage through which the gas flows.

The aerosol size distribution can be estimated from the empirical equation of Nukiyama and Tanasawa(ref.2):

$$\frac{d}{do} = \frac{585}{v}\left(\frac{\sigma}{\rho}\right)^{0.5} + 597 \left[\frac{n}{(\sigma \rho)^{0.5}}\right]^{0.45} \left[\frac{1000 \text{ Vliq}}{\text{Vair}}\right]^{1.5},$$

where the denotations are:

d, the mean Sauter droplet diameter and
do the mean droplet diameter in micrometers,

σ, the surface tension in dynes cm^{-1},

ρ, the density in g cm^{-3}
n, the viscosity in poises,

v, the velocity of the aspirating gas in m s^{-1}, and
Vliq and Vair the respective volumes per second of the liquid fuel and the aspirating air.

In our case, the first term on the right hand side of the equation predominates(ref.3), as

$$\frac{\text{Vliq}}{\text{Vair}} < 10^{-4}.$$

The schematic diagrams of the liquid aerosol generator are shown in figures 1(a) and 1(b). It can be seen that the fuel flow and the aspirating gas are separately controlled by the stainless steel needle valves.

For fire safety reasons, the brass fuel tank is allowed to contain a maximum of 50 cm^3 of fuel, an amount which would provide a burn-time of approximately 30 s; or if spilt accidently, a short duration fire would be contained easily.

The capillary tube was made from the stainless steel hypodermic needles readily available. Four hypodermic needles of length 20 mm were chosen with internal diameters 0.27 mm, 0.40 mm, 0.55 mm and 0.85 mm, and external diameters 0.50 mm, 0.63 mm, 0.80 mm and 1.10 mm, respectively.

Three gas nozzles, made from brass, were used to accommodate the capillary needles, and they were of internal diameters 0.80 mm, 1.00 mm and 1.30 mm.

The choice of four capillary tubes and three nozzles makes the aerosol generator sufficiently versatile for use with fuels of substantial difference in surface tension, viscosity and density; and allows the production of aerosols of droplet sizes in the micrometer range.

High fuel flow rates were obtained by applying a constant pressure of 100 kPa on the fuel. The hydrostatic pressure due to the fuel is less than 0.5 kPa and is negligible compared to the applied pressure.

When the system was operated with the appropriate adjustment of the fuel flow valve and the gas pressure valve, a maximum of the fuel flow rate of 2.5 mL s^{-1} was obtained under the folowing conditions:

Applied aspirating gas pressure	= 100 kPa
Applied pressure on fuel	= 100 kPa
Capillary needle	= 0.85 mm (internal diameter)
Gas nozzle	= 1.30 mm (internal diameter)

A stainless steel impact bead of diameter 3.2 mm placed 2 mm in front of the nozzle splits the droplet further, and simultaneously spreads the aerosol cloud radially. This device was found to be necessary to produce the extended and self-sustaining aerosol flames and therefore was included in the design.

Further regulation of the fuel flow rate and the aspirating gas velocity is possible by controlling the relative position of the capillary needle with respect to the gas nozzle.

It was found experimentally that the flame stability increased when the nozzle housing was rotated one turn away from the main assembly. This configuration was retained for the calibration of the aerosol generator.

3. RESULTS AND DISCUSSIONS

3.1 Calibration

The aerosol generator was calibrated for the fuel flow rate and the aspirating gas pressure in terms of the settings of the fuel valve and the pressure valve, under the following conditions:

Aspirating gas	: Nitrogen at 100 kPa
Liquid fuel	: Kerosene
Capillary needle	: 0.85 mm (internal diameter)
Gas nozzle	: 1.30 mm (internal diameter)
Position of nozzle	: 1 turn away from the main assembly

The Calibration Chart constructed in this manner provides a convenient reference of the fuel flow rate and the aspirating gas pressure when the aerosol generator is operated in future under the same conditions.

For the pressure calibration, a pressure gauge with the range of 0 to 100 kPa was used, and measurement was made with the fuel flow valve closed. The pressure calibration curves are shown in figure 2.

It is evident from figure 2 that the aspirating gas pressure drops when the gas nozzle housing is adjusted one turn away from the main assembly. This is expected as the effective cross-sectional area where the aspirating gas leaves the nozzle increases when the capillary needle is withdrawn from the nozzle (see figure 1(a)).

For the calibration of the fuel flow rate, the measurements of the fuel flow rate were made as the fuel control valve was successively adjusted, at a constant setting of the pressure control valve. The actual aspirating gas pressures at different settings of the fuel flow valve were simultaneously measured. The calibration curves for the actual aspirating pressure and the fuel flow rate are shown in figures 3(a) and 3(b), each of the curves corresponds to a preset pressure valve.

Inspection of figures 3(a) and 3(b) reveals two aspects of the kerosene generation in that when the aspirating gas pressure valve opens wider to increase the pressure:

(a) the actual pressure measured in this case is higher than the corres ponding measurement when no fuel flows; and

(b) the fuel flow rate decreases.

This first effect is not unexpected as the total pressure is now not only due to the nitrogen gas, but also to the kerosene vapour and the kerosene aerosols with droplet diameters less than 50 µm which behave like a gas(ref.4,5).

The second effect might appear to be surprising, but a further examination of the position of the capillary needle relative to that of the gas nozzle suggests that "blow-back" occurs, and it increases with the preset aspirating gas pressure.

This result of lower fuel flow giving rise to higher vapour pressure indicates a larger contribution to the vapour pressure by aerosols necessarily of smaller mean droplet size.

Such interpretation is supported by the arguments that:

(a) The mean droplet size is inversely proportional to the velocity of the aspirating gas(ref.2).

(b) Aerosol droplets smaller than 50 µm behave like a gas(ref.4). From gas theories, it can be argued that larger vapour pressure must be contributed by more aerosols of smaller droplet sizes, for a constant mass of kerosene fuel.

Hence, for our aerosol generating system operated under the conditions previously described, the vapour pressure could be used as a measure of the mean droplet size of the kerosene aerosols, especially when the fuel flow rate is constant. This interpretation will be verified experimentally in the next section.

Using the data in figures 2, 3(a) and 3(b), the vapour pressure and the fuel flow rate of kerosene were plotted against the pressure control valve setting for each predetermined fuel control valve, as shown in figures 4(a) and 4(b). Each value of the vapour pressure is derived by taking the difference in aspirating gas pressures for no fuel flow and fuel flowing at a particular setting of the pressure and fuel control valves.

Finally, more detailed calibration curves of the vapour pressure versus the fuel flow rate for various settings of the pressure and fuel control valves were constructed in figure 5.

As is evident from figure 5, a single fuel flow rate which corresponds to different vapour pressures, or a single vapour pressure which corresponds to different fuel flow rates can be obtained from more than one appropriate combined setting of the pressure and fuel control valves.

3.2 Particle sizing

It is obvious that whenever possible, the particle sizes of the aerosols must be measured. However, in the absence of a reliable particle sizer, another more conveniently measured quantity, vapour pressure in our case, is used to implicate mean particle size.

This conjecture shall be experimentally verified.

Experimentally, it is extremely difficult to vary the vapour pressure at a constant fuel flow rate by adjusting only the pressure and fuel control valves of the aerosol generator. However, it is observed from figure 5 that there are eight convenient settings which correspond to vapour pressures from 2.40 kPa to 8.18 kPa and fuel flow rates from 1.90 mL s^{-1} to 2.08 mL s^{-1}. The fuel flow rates of such narrow spread of 0.18 mL s^{-1} shall be assumed to be constant.

Measurements of the droplet sizes of the kerosene aerosols were performed on a Malvern particle sizer, Model 2200, for the eight samples of aerosols.

The analysis shows that the aerosols generated are polydispersed, as shown in figure 6.

From the attendant data on the particle size bands and the weight in the size bands, the arithmetic mean for the droplet diameters in each measurement was calculated. The mean droplet diameters were then plotted against their corresponding vapour pressures, as in figure 7.

An excellent correlation, evident in figure 7, confirms that the vapour pressure is a good measure of the mean droplet diameter of aerosols produced in our aerosol generating system.

The verification is very useful to our future investigation of spray flames, as the Malvern 2200 particle sizer is available to us only on a very limited basis.

4. CONCLUSION

A liquid aerosol generator of the dispersion type was constructed, and the kerosene aerosols produced were polydispersed.

The mean droplet diameters measured were found to be inversely proportional to the vapour pressures of the kerosene aerosols.

In our further work on spray flames, the vapour pressures of kerosene aerosols will be used to represent the mean droplet diameters.

5. ACKNOWLEDGEMENT

We acknowledge the workshop support provid d by Advanced Engineering Laboratory in the manufacture of the aerosol generator, and the assistance of Mr Peter Whitehead in operating the Malvern particle sizer made available to us by Weapons Systems Research Laboratory.

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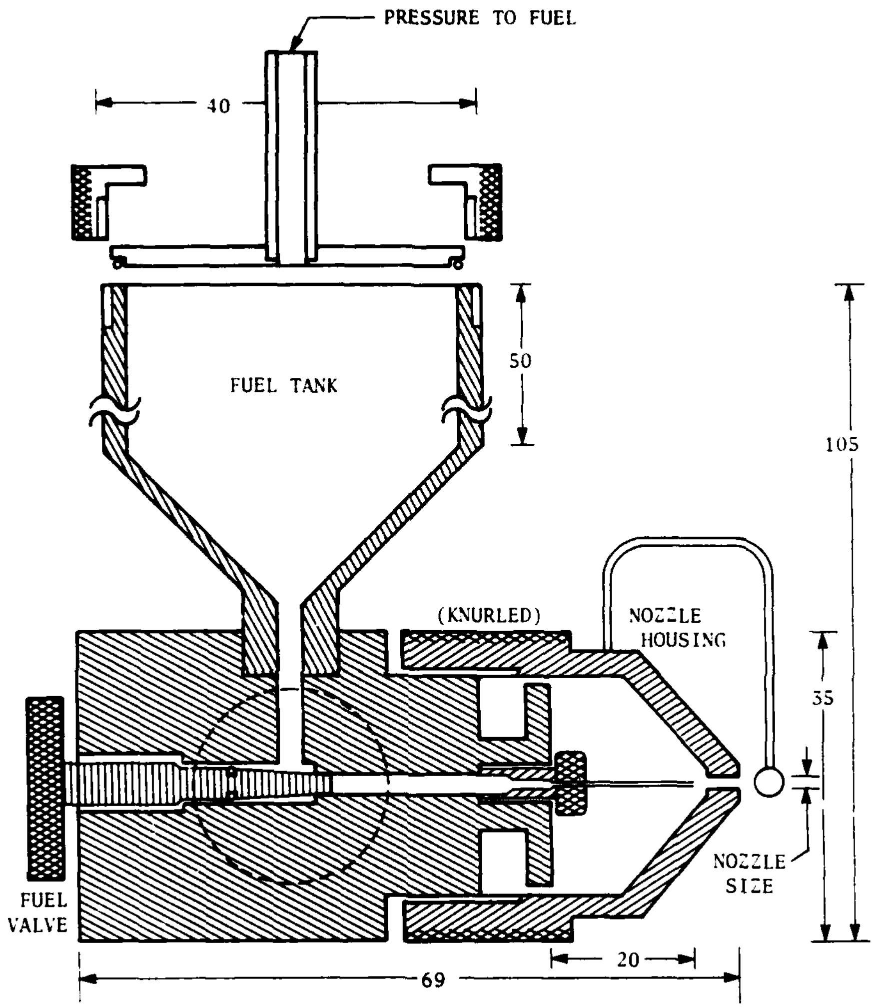

Figure 1(a). Schematic elevation of aerosol generator (dimensions in mm)

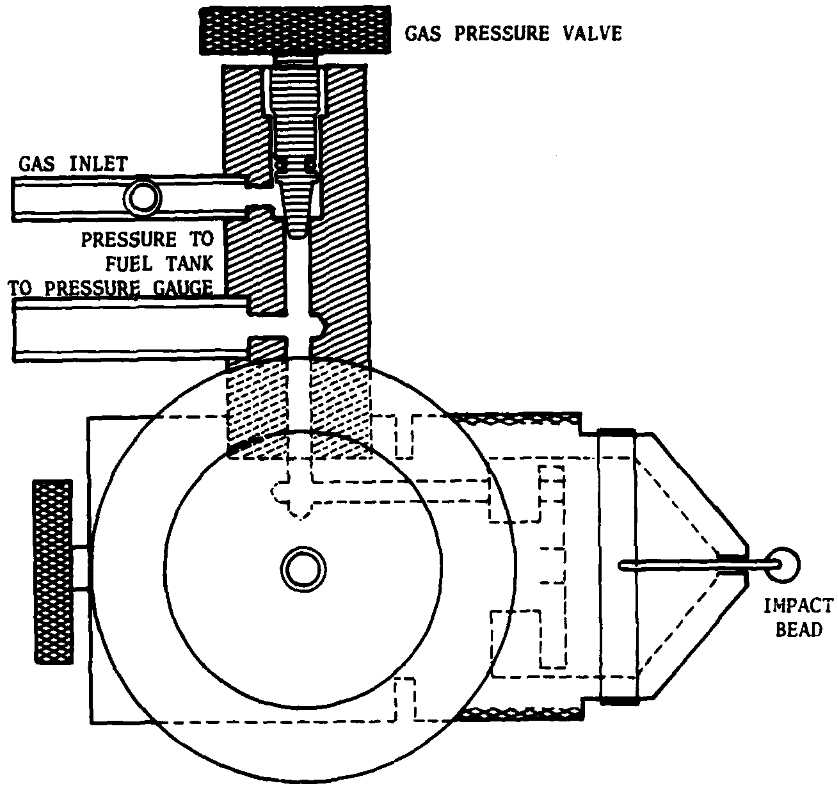

Figure 1(b). Schematic plan view of aerosol generator

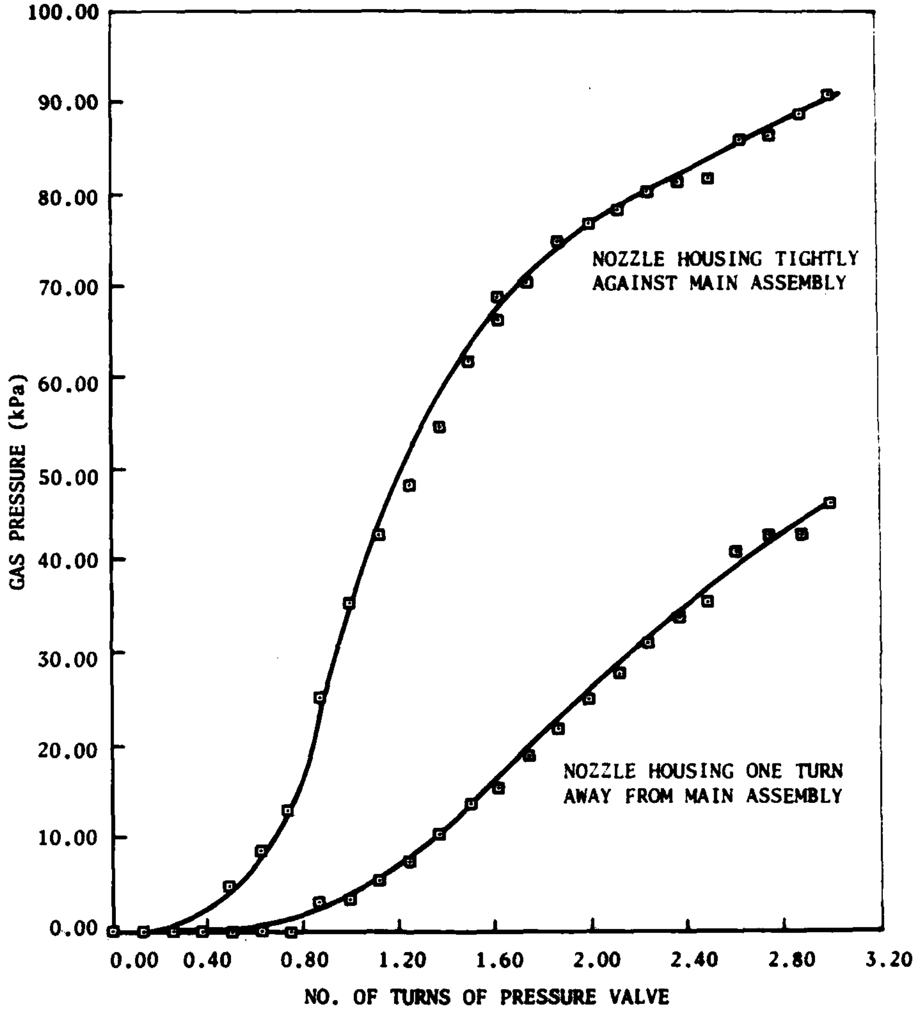

Figure 2. Calibration curve for the aspirating gas pressure versus pressure valve setting

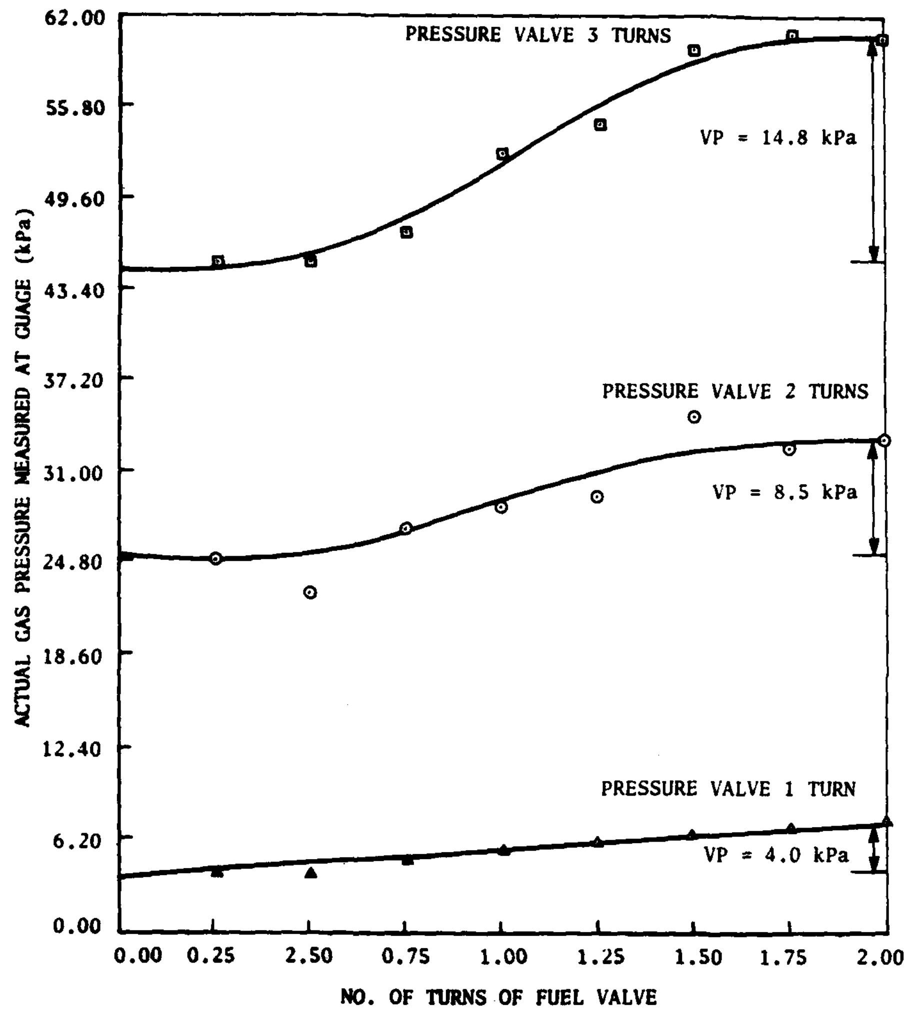

Figure 3(a). Calibration curve for the total aspirating gas pressure versus fuel flow valve setting, when fuel actually flows

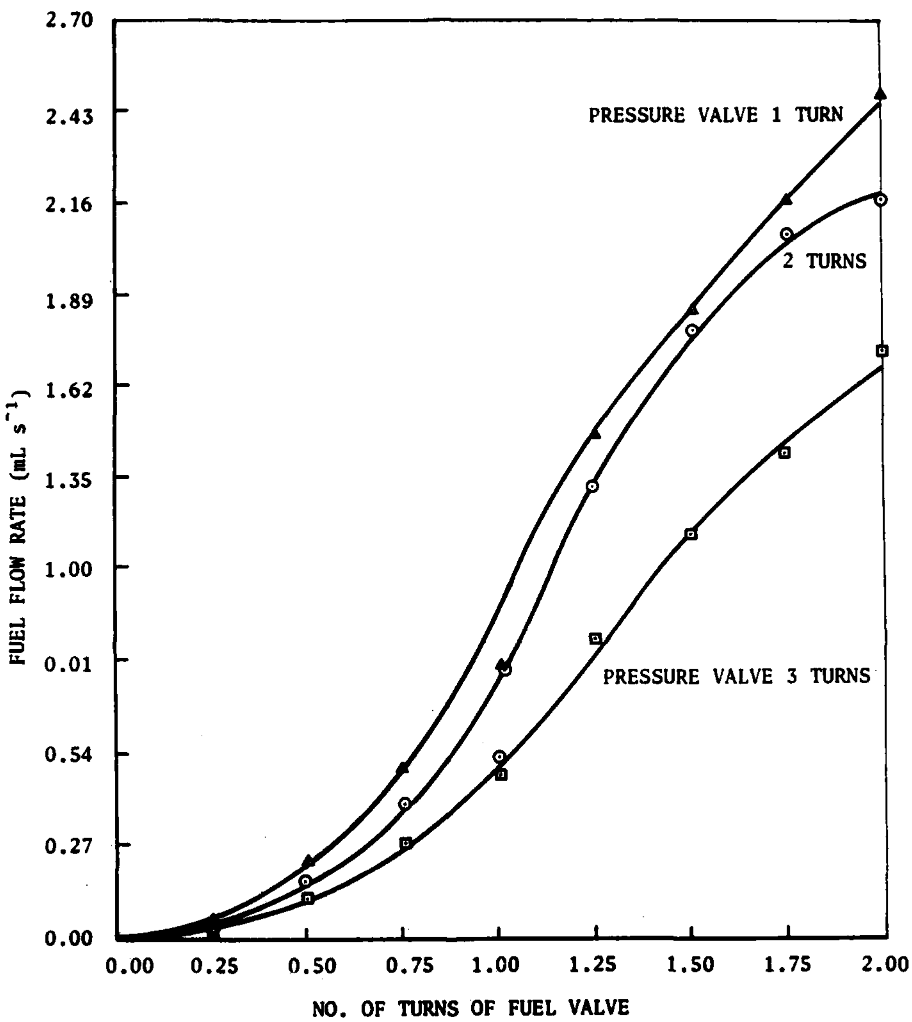

Figure 3(b). Calibration curve for the fuel flow rate versus fuel flow valve setting at a preset pressure valve

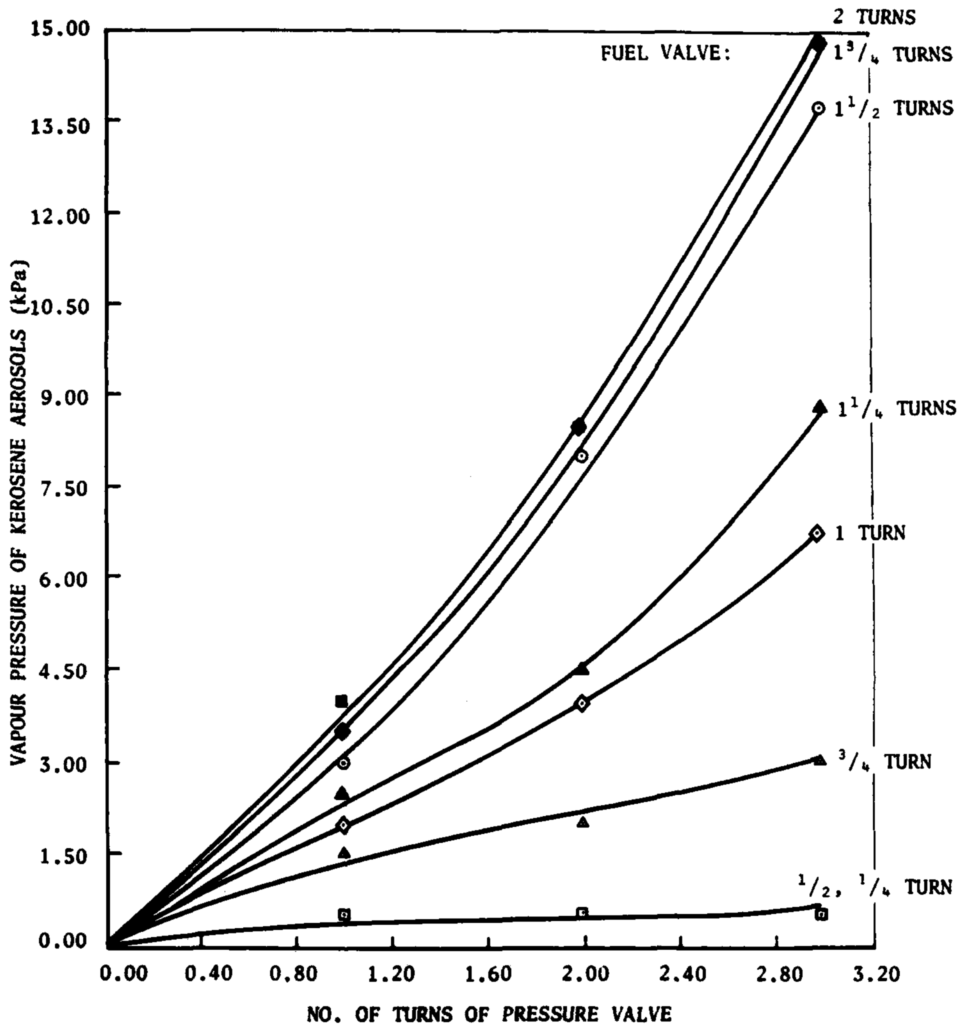

Figure 4(a). Vapour pressure of kerosene aerosols versus pressure valve setting for a preset fuel flow valve

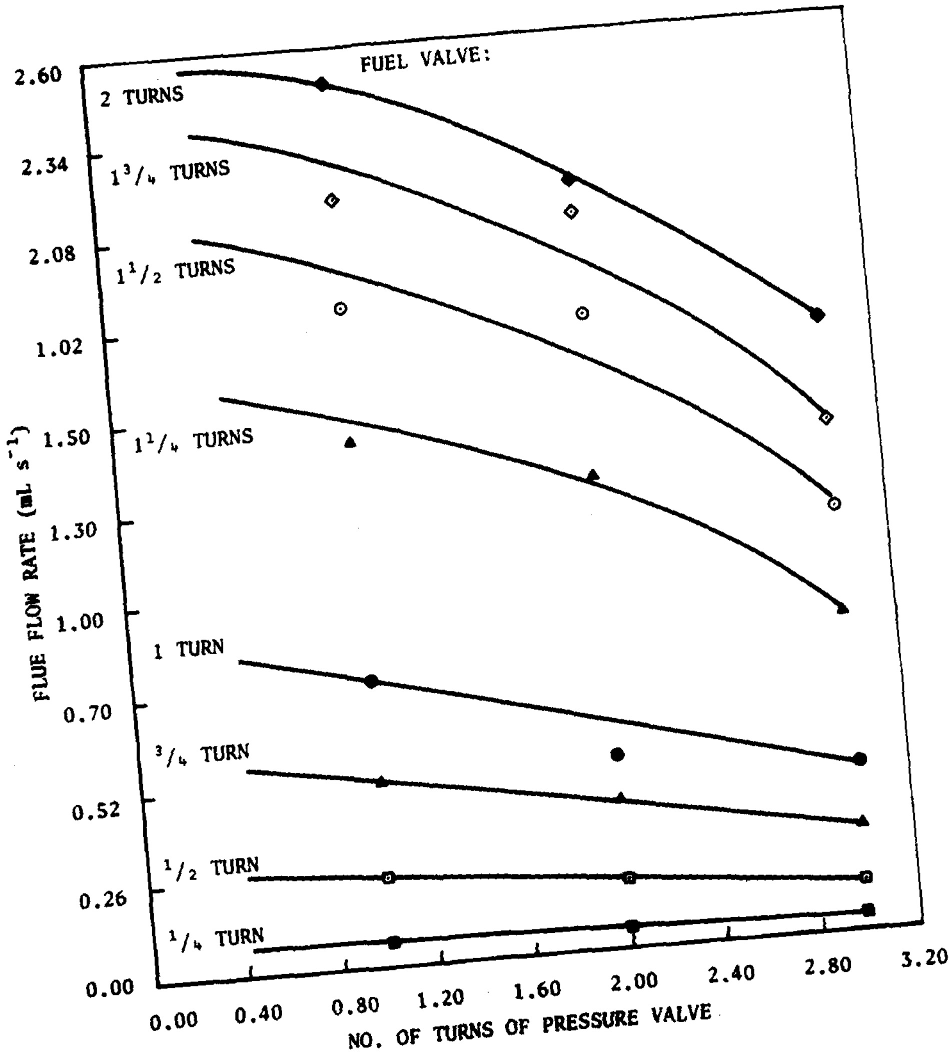

Figure 4(b). Flow rate of kerosene fuel versus pressure valve setting for a preset fuel flow valve

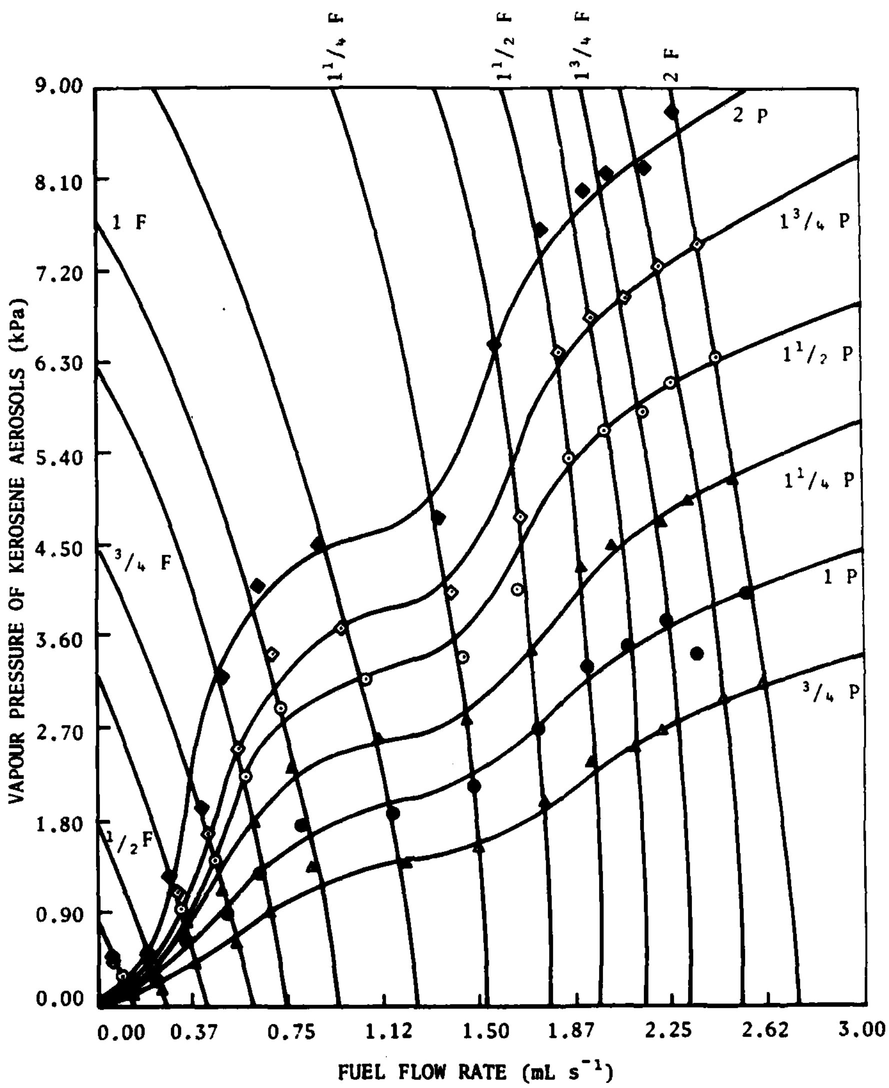

Figure 5. Vapour pressure of kerosene aerosols as a function of flow rate of kerosene liquid for various settings of fuel flow valve and aspirating gas pressure valve (F and P represent the fuel valve and the pressure valve setting respectively)

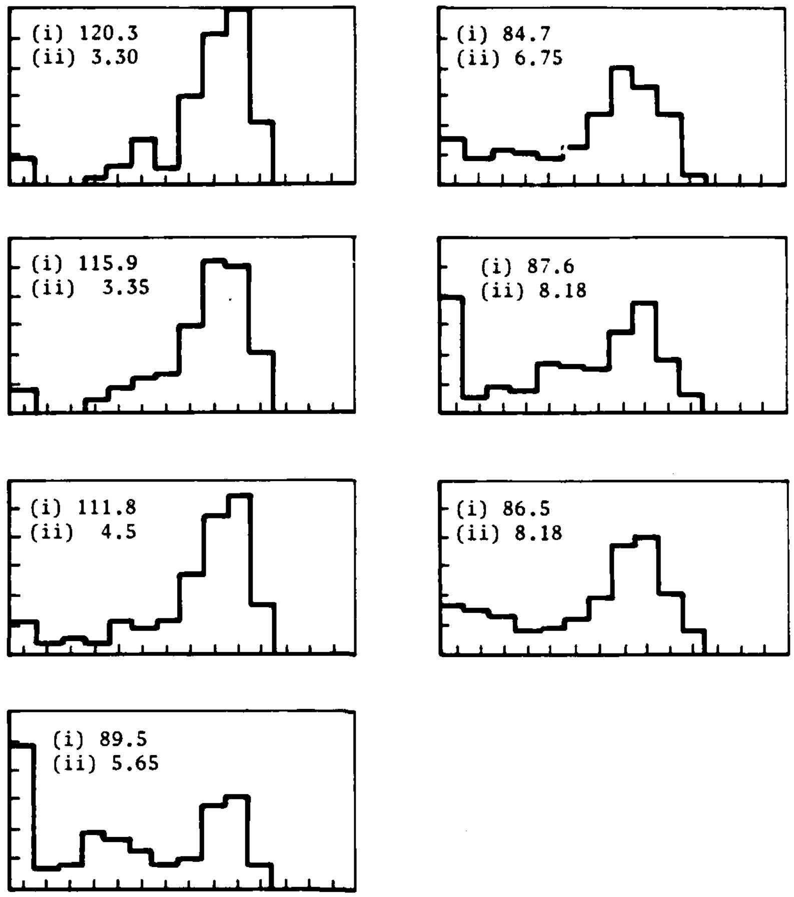

Figure 6. Particle size bands (X-axis) versus weight in bands (Y-axis) of kerosene aerosols (i) Mean droplet diameter μm) (ii) Vapour pressure (kPa)

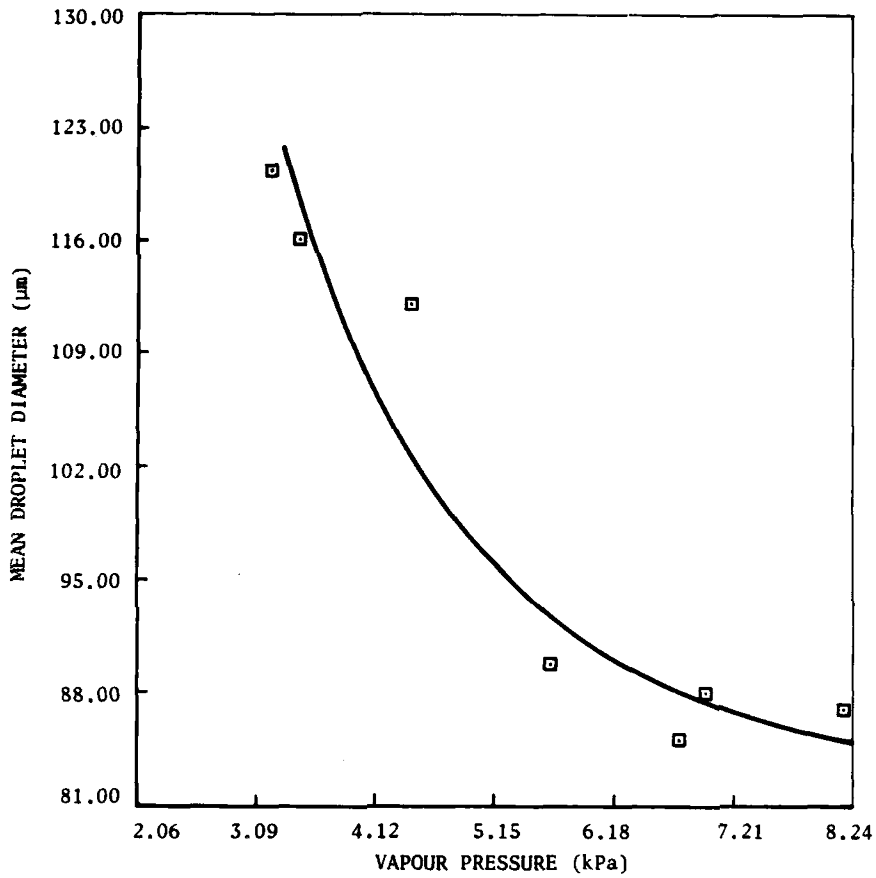

Figure 7. Mean droplet diameter versus vapour pressure of kerosene aerosols

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